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MAXIMUM TNT EQUIVALENCE OF NAVAL PROPELLANTS

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ABSTRACT

As part of the Naval Explosives Safety Improvement Program (NESIP), two series of tests have been conducted to determine the maximum TNT equivalence of Naval propellants. Airblast and detonation velocity measurements were made on M26 and NACO 5-inch propelling charges, MK 10 (3.25"), MK 16 (5"), MK 40 (2.75"), MK 58 (SPARROW), MK 37 (ASROC), MK 27 (TARTAR), MK 30 (STANDARD) rocket motors, and TNT cylinders. The MK 40 and MK 37 motors detonated high order and had a TNT equivalence of 70-75%. The other propellants had TNT equivalencies ranging from 5 to 50%. Recommendations are also made about possible revisions to OP-5. Instead of the 25 percent equivalency now used for guided missile propellants, 100 percent is recommended for double base and composite/double base materials, 50 percent for composite materials, and 125 percent for high energy propellants.

INTRODUCTION

Other studies have shown that solid propellants can detonate, and, even if not detonating, can be made to react rapidly enough to have a significant explosive yield. If this is the case, then many solid propellants and the devices utilizing them could have significant TNT equivalencies.

Current Navy practice, as stated in Navy publication OP-5 (Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation, and Shipping)[1] is to basically ignore propellant contributions to the determination of New Explosive Weight (NEW) (with the exception listed below).

OP-5 states in Section 5-3.2 (Basis for Q-D Determinations and Computations):

"For shore stations . . . the net weight of explosives for each type of ammunition item shall be computed as follows . . .

> Fixed Ammunition - The net weight of the explosives in the projectile or warhead; the smokeless powder in the cartridge case is disregarded in this instance.
>
> Rocket Warheads and Motors packed together (Assembled or Unassembled) - the net weight of the explosives in the rocket warhead; the propellant is disregarded.
>
> Guided Missiles - the net weight of the explosive in the warhead plus 25 percent of the propellant weight of the motor.

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[1] Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation and Shipping, NAVSEA OP-5 Vol. I, revision 11, 15 May 1983.

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DTIC AND NTIS

On board ship, the explosives and ammunition are stowed relatively close to each other and a detonation in the mass-detonating part of the cargo would receive considerable support from categories that are normally considered to be fragment or fire hazards.

Accordingly, the total quantity of mass-detonating explosives may be calculated by using the weight of HE filler and the weighted values for different types of propellants and other fillers in relation to TNT. For a general approximation, use the total quantity of HE plus 25 percent of the propellant."

Several questions have been raised about this 25 percent equivalency factor for solid propellants. Some propellants, and even classes of propellants may not detonate nor even react violently; for these, the equivalency is close to 0. Others may react violently, but not sustain a true detonation; for these, the TNT equivalency is between 0 and 100 percent. Still others, especially the newer high energy propellants may behave like ideal explosives and detonate with a TNT equivalency greater than 100 percent.

To address this problem the Naval Explosives Safety Improvement Program (NESIP) has conducted a two-phase experimental program to determine the maximum TNT equivalency for several rocket motors and two gun propellant cartridges currently in the inventory. In addition, a literature search has been conducted on similar research efforts by other groups.

In order to determine a maximum TNT equivalency, actual missile motors or propellant cartridges were tested. The size of the explosive booster was chosen to nominally represent at least 10 percent of the total propellant weight. It was felt that this would represent a "worst case" condition which would yield a maximum equivalency.

EXPERIMENTAL PROGRAM

Several types of propellant were investigated--two gun propellants and five rocket propellants. The gun propellants were M26 and NACO, each contained in standard 5"/54 propellant cartridges. The rocket propellants considered were those contained in the following motors; (1) MK 58 SPARROW, (2) MK 37 ASROC, (3) MK 30 STANDARD sustainer, (4) MK 27 Improved TARTAR, (5) MK 16 5" ZUNI, (6) MK 40 2.75" MIGHTY MOUSE, and (7) MK 10 3.25". These were fired in two phases: items (1) - (3) and the gun propellants in Phase I, and items (4) - (7) in Phase II.

NACO is primarily nitrocellulose (with stabilizers) and represents single base gun propellants. M26 is nitrocellulose, nitroglycerine, and stabilizers and represents double base gun propellants.

The MK 58 SPARROW motor is composed of ammonium perchlorate, aluminum, and a rubbery binder. The MK 30 STANDARD propellant is composed of ammonium perchlorate and a rubbery binder. The MK 27 TARTAR propellant is composed of ammonium perchlorate/polyurethane/aluminum and ammonium perchlorate/nitroguanidine/polyurethane. The MK 37 ASROC, MK 40, and MK 10 MIGHTY MOUSE propellants were N5, and the MK 16 was X-8, all nitrocellulose, nitroglycerine, plus a binder.

The SPARROW, STANDARD, and TARTAR propellants were chosen to represent composite propellants; the MK 37, MK 40, and MK 16 were chosen to represent double-base propellants.

As part of the same program, TNT comparison charges were also detonated. Three sizes were used, corresponding to the three nominal propellant sizes. These charges were designed to have similar length-to-diameter (l/d) ratios as the corresponding motors for that charge size. In addition, some of the gross internal features of the propellant grains were also modeled.

Also included in the firing program were replicates of the explosive boosters themselves. These boosters were conically-ended cylinders. They were fired at distances above the ground corresponding to their locations on the corresponding rocket motors (this eliminates any height-of-burst effects in the measurement of the booster output). The complete firing program is outlined in Table 1.

All test items were oriented with their long axis vertical. All were fired over a steel witness plate 3 inches thick. The motors were placed with their nozzles on the bottom--in contact with the witness plate. Similarly, the propellant cartridges were placed with their base plates downward.

The boosters were then emplaced on the top of each test item. If the propellant grain could not be directly exposed to the booster, the interstices between and around the booster and the grain were filled with Composition C-4.

The stated purpose of the tests was to determine the maximum TNT equivalency of these propellants. Concommitant with this is the question, "Did the material detonate, deflagrate, or simply rapidly react?" The TNT equivalency is determined by the measurement of airblast. The violence of the reaction was determined in three ways: (1) high-speed photographs of the event, (2) detonation velocity mesurements along the length of the case, and (3) by the type of dent left in the witness plate.

GENERAL OBSERVATIONS

There was no doubt that the TNT standard charges detonated high order. The damage to the witness plate for each charge ranged from denting the plate to punching a hole, and finally rupturing the plate, depending upon the charge size.

Neither of the gun propellant types (M26 and NACO) appeared to detonate. The witness plates were not dented after. Large pieces of the cartridge cases remained relatively intact (the sides peeled back like a banana). Significant quantities of unreacted propellant were scattered over the test area. (No measurements were made on the quantity of unreacted propellant. However, estimates by observers on site were approximately 10 to 20 percent.)

The SPARROW motors did not appear to detonate. The witness plates were not dented. Large pieces of case material were thrown from ground zero. High speed photographs showed burning propellant being thrown from the ground zero area. Small quantities of unreacted propellant were also located after each shot.

Table 1 Firing Program

Phase	Charge Type	Number of Shots	Nominal Explosive/ Propellant Weight (lb)	Nominal Booster Weight (lb)	Nominal Case Weight (lb)
I	Small TNT standard	3	48.0	5.2	4.0
I	Medium TNT standard	3	145.0	12.5	10.0
I	Large TNT standard	3	351.0	59.0	17.0
I	Small booster	1	-	5.2	-
I	Medium booster	1	-	14.1	-
I	Large booster	1	-	59.2	-
I	MK 58	3	133.0	16.6	78.0
I	MK 37	3	233.0	41.6	140.0
I	MK 30	1	362.0	63.0	181.0
I	5"/54 prop (M26)	3	21.1	5.2	8.5
I	5"/54 prop (NACO)	3	20.6	5.2	8.5
II	Small TNT standard	2	48.0	6.6	4.0
II	B1 (small booster)	2	-	2.0	-
II	B2 (medium booster)	2	-	6.6	-
II	B3 (large booster)	2	-	34.5	-
II	MK 10	2	24.0	6.6	36.0
II	MK 16	2	33.5	6.6	29.0
II	MK 40	3	5.9	2.0	5.5
II	MK 27	1	558.0	35.0	206.0

The ASROC motors appeared to achieve a high order detonation. The witness plates bore the imprint of the nozzle/venturi area of the motor. The motor case material was fragmented into many small fragments--reminiscent of general purpose bomb fragments.

The STANDARD and TARTAR motors did not appear to achieve a high order detonation. Because of the configuration of the motor (a blast tube extending below the propellant grain), even if a high order detonation had been achieved, no plate dent was expected. However, large portions of the case and base material were recovered intact. Large pieces of propellant grain were recovered after the TARTAR firing.

The MK 10 and MK 40 appeared to detonate high order. The MK 16 threw broken pieces of propellant grain over the entire test area.

DETONATION VELOCITY

Detonation velocity was measured in two ways-electronically, using crush switches placed along the outside of the case, and photographically--utilizing high speed cameras operating at 25,000 to 40,000 pictures per second.

Only two items appeared to achieve a true high order detonation--the TNT shots and the ASROC motors. The average detonation rates measured were in excellent agreement with those reported in the literature: For TNT, an average value of 22,600 ft/s (6890 m/s) compared with a value of 22,400 ft/s (6830 m/s);[2] for ASROC motors, a value of 23,700 ft/s (7220 m/s), compared with a value of 23,000 ft/s (7010 m/s) for N-5 propellant.[3] Because of the booster size involved, the ASROC values may be high because the wave was initially overdriven.

The detonation velocity system was behaving erratically during the MK 40 tests; thus no detonation velocity information was obtained. In all of the other cases, the detonation wave apeared to die out--either the pins were not crushed at all, or the slope of the detonation wave position-time indicates the wave was decelerating.

AIRBLAST

The airblast recorded on the program included peak presure, positive duration and impulse, as well as shockwave time of arrival. Least squares curves of the form

$$\ln(f) = A + B\,[\ln(R)] + C\,[\ln(R)]^2$$

were fitted to pressure-distance and impulse-distance data. Here f represents either peak pressure in psi or positive impulse in psi-ms, ln represents the

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[2] Engineering Design Handbook: Explosive Series--Properties of Explosives of Military Interest, Army Materials Command AMC Pamphlet No. 706-177, 29 Jan 1971.

[3] Levmone, S. and Swatosh, J. J., Jr., Blast Parameters and Other Characteristics of N5 Propellant, IIT Research Institute Technical Report ARLCD-TR-77023, Dec 1977.

natural logarithum, R is the range in feet from the charge to the measurement location, and A, B, C are fitting constants.

Figures 1 and 2 present the fitted pressure-distance and impulse-distance curves.

EQUIVALENT WEIGHT CONCEPTS

The equivalent weight of a particular explosive is the weight of some assumed standard explosive (like TNT) required to produce a selected shockwave parameter of equal magnitude to that produced by a unit weight of the test explosive in question. A given explosive will have several equivalent weights, depending on the shockwave parameter selected; i.e., it will have an equivalent weight based on peak overpressure, positive impulse, time of arrival, positive duration, etc. The equivalent weight, based on any given blast parameter, varies, also, as a function of distance from the charge; i.e., the pressure-distance or impulse-distance curve for explosive X is not necessarily parallel to that of the standard. For many purposes, it is sufficient to cite a single equivalent weight number--the average of equivalent weights over some range of pressure.

The basic tenets of similitude imply that comparisons be made between charges of the same shape, confinement, and geometry of interest. The results of such a comparison represent a true measure of the explosive performance.

This is not to imply that comparisons against non-similar are wrong--merely that the results must be interpreted more carefully. For hazard classification purposes, it must be remembered, the DOD classification procedures[4] state that the standard of comparison to be used is a TNT hemisphere.

YIELD CONCEPTS

Utilizing techniques developed and defined in the analysis of nuclear blast yields, an absolute yield (in megacalories) can be determined for any pressure-distance curve. These concepts have been refined and incorporated into the Unified Theory of Explosions (UTE) by F. Porzel.[5] The technique was developed for spherical or hemispherical detonations, but can be applied to cylindrical data as well.

Two "test cases" are described to demonstrate the method: (1) KING nuclear fireball data and (2) the Air Force Weapons Laboratory 1 KT Nuclear Blast Standard.

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[4]Department of Defense Explosive Hazard Classification Procedures, DOD Publication TB700-2 (NAVSEAINST 8020.3, TO 11A-1-47, DLAR 8020.1), Mar 1981.

[5]Porzel, F. B., Introduction to a Unified Theory of Explosions (UTE), NOL TR 72-209, Sep 1972.

The KING fireball data are among the best pressure-distance data in existence: a high yield, air dropped, all fission weapon with negligible mass effect resulting in a perfectly spherical fireball. It spans a pressure range of 4,600 to 190,000 kPa. radio chemistry gave a yield of 545 KT.[6] The UTE yield methodology gave 586 KT. The differences are within the round-off errors in tabulating the original data, let alone possible experimental uncertainty.[6]

The AFWL 1 KT Nuclear Blast Standard is not data but a HULL hydrocode calculation covering the pressures of 7 to 10^6 kPa. The UTE yield derived from the pressure-distance curve is 0.997 KT±14.6 percent--again good agreement.[6]

EQUIVALENT WEIGHT/YIELD ANALYSES

All of the data presented in Figures 1 and 2 were corrected for the effects of the boosters; i.e., the effects of the boosters were subtracted out of the pressure-distance and impulse-distance data. Using these booster-corrected data, equivalent weights based on both peak pressure and positive-impulse were computed as well as a UTE yield for each case. Figure 3 presents an example of the equivalent weight data determined for some of the Phase I results. All of the methods yield essentially the same results. These are summarized in Table 2.

Table 2 Average Equivalent Weight Summary*

TYPE	MATERIAL	TNT EQUIVALENCE (%)
Gun - Single Base	NACO	5[1]
Gun - Double Base	M26	18[1]
Rocket - Composite	MK 58 (SPARROW)	5
	MK 27 (TARTAR)	2
	MK 30 (STANDARD)	36
Rocket-Double Base	MK 37 (ASROC)	75
	MK 16	16
	MK 10	52
	MK 40	71

*[1]5" propellant cartridge

[6]Porzel, F. B., Yield and Blast Analyses with a Unified Theory of Explosions, presented at the 20th Department of Defense Explosive Safety Board Seminar, Norfolk, Virginia, Aug 1982.

Other researchers[7,8] have also investigated NACO and M26 propellants--not in propellant cartridges but in shipping containers. For NACO, they found equivalencies up to 14 percent for 15" diameter or larger shipping containers. For M26, they found a 125 percent equivalency for 15" diameter containers and larger--an obvious charge size effect.

SUMMARY

Propellants, by definition, are energetic materials. Thus, it should come as no surprise that many propellants exhibit significant TNT equivalencies. Even though most do not achieve a high order detonation, they react fast enough to contribute to the airblast produced. It must be remembered that this program was designed to determine the worst case results.

Generally, single base and composite propellants do not appear to detonate (depending upon their critical diameters); double base and high energy propellants do detonate. A major factor keeping the M26 propellant from detonating in the propellant cartridges is the diameter--5 to 6 inches. Anything much larger would probably detonate.

The SPARROW and TARTAR results are consistent with those reported in the literature--but depending on the size of the motor, equivalencies of 40 to 50 percent can be obtained.

Based on the data obtained on this program, material available in the literature, and discussions with NAVSEA Safety, the following (Table 3) suggested revision to OP-5 was presented to the DDESB in August 1983.

Table 3 Suggested Revision to OP-5

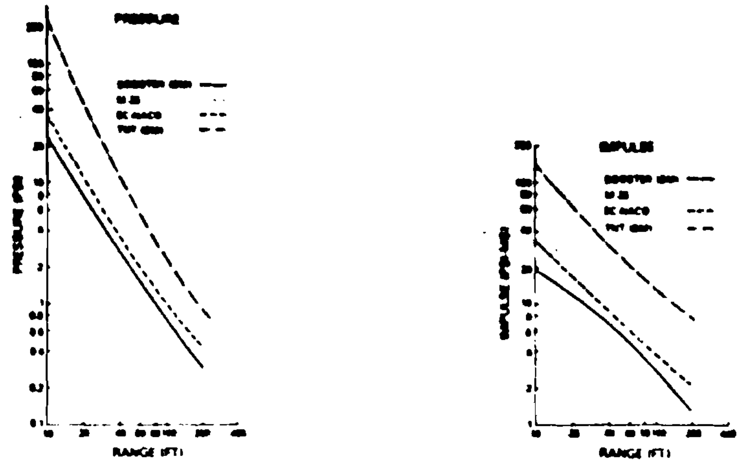
Gun Propellants (5" diameter or less)	0%*
Gun Propellants (>5" diameter)	100%
Composite Rocket Propellants	50%
Double Base Rocket Propellants	100%
Composite/Double Base Rocket Propellants	100%
High Energy Propellants	125%

Use the above values unless a maximum TNT equivalence for the particular motor/materials combination has been experimentally determined.

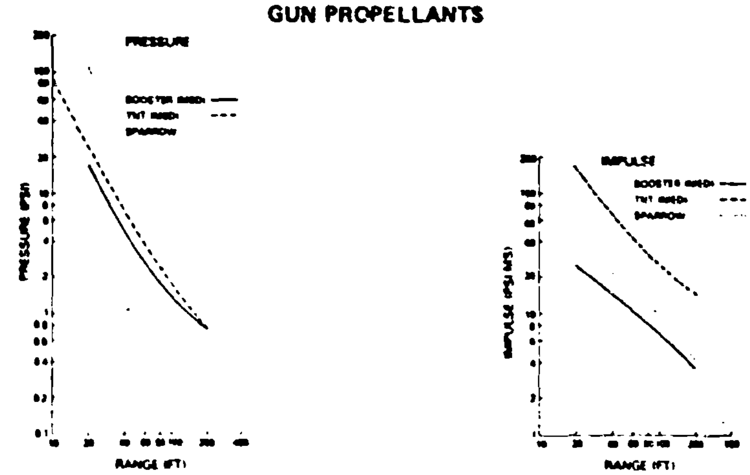
*5-inch diameter charges are below the critical diameter for most charges; moreover it is extremely unlikely that a sufficient stimulus can be brought to bear on these rounds, as they are generally stored separately from their projectiles.

[7]Swatosh, J. J., Jr. and Cook, J. R., Blast Parameters of M26E1 Propellant, IIT Research Institute Report TR 4901, Dec 1976.

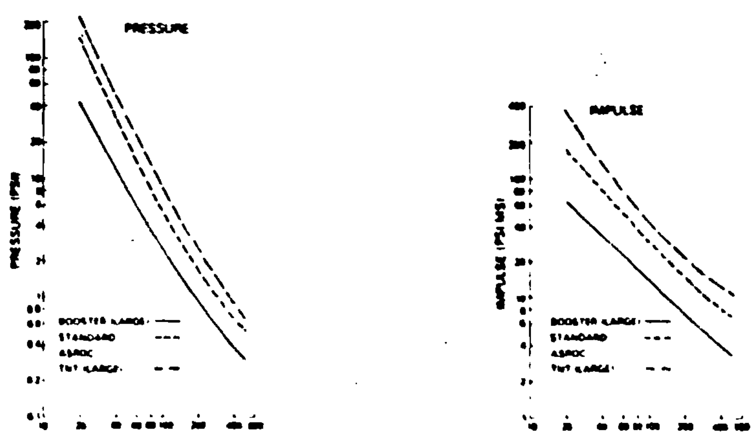
[8]Swatosh, J. J., Jr. and Cook, J. R., Blast Parameters of BS-NACO Propellant, IIT Research Institute Report ARLCD-CR-77003, Apr 1977.



GUN PROPELLANTS

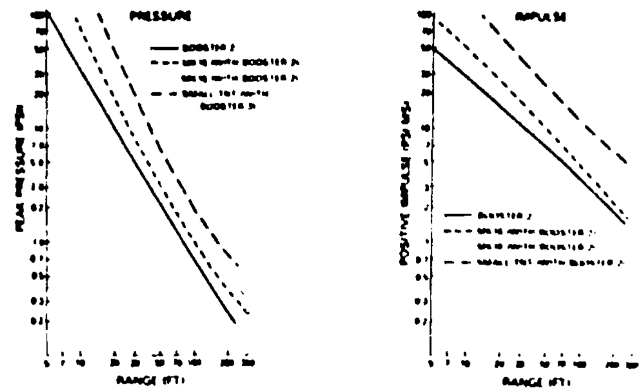


SPARROW

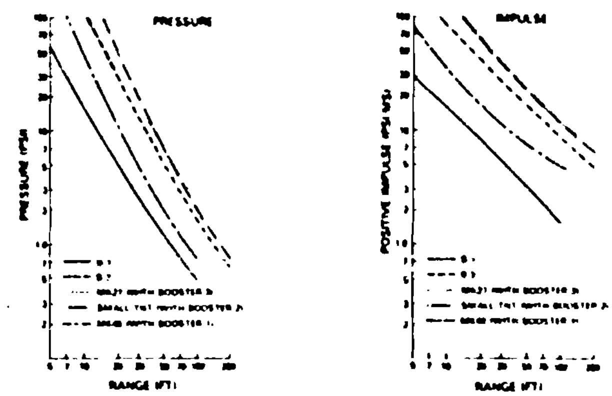


ASROC AND STANDARD

FIGURE 1 PHASE I AIRBLAST COMPARISONS



MK 16 AND MK 40



MK 40 AND MK 27

FIGURE 2 PHASE II AIRBLAST COMPARISONS

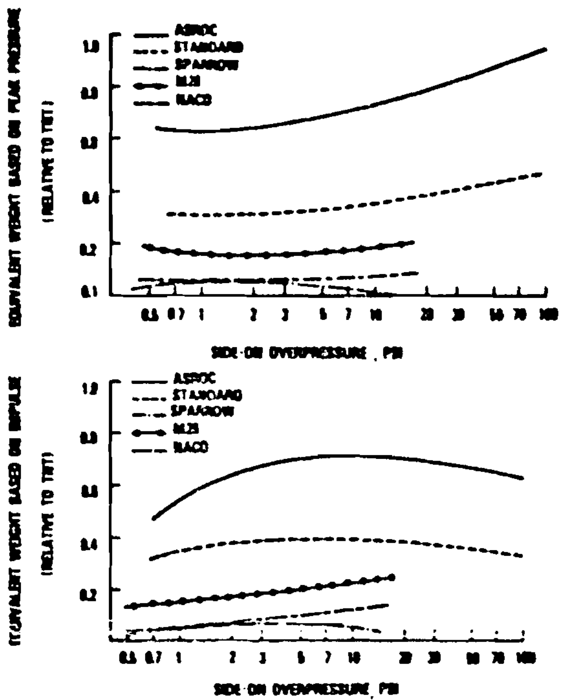


FIGURE 3 PHASE I EQUIVALENT WEIGHT VS. PRESSURE